Comparison between outcomes using preferred gain and prescribed gain formulae in experienced adult hearing aid users

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CERTIFICATE

This is to certify that this dissertation entitled **"Comparison between outcomes using preferred gain and prescribed gain formulae in experienced adult hearing aid users"** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration No: 09AUD001. This has been carried out the under guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Comparison between outcomes using preferred gain and prescribed gain formulae in experienced adult hearing aid users"** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this master's dissertation entitled **"Comparison between outcomes using preferred gain and prescribed gain formulae in experienced adult hearing aid users"** is the result of my own study under the guidance of Dr. Vijaya Kumar Narne, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

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~William Shakespeare

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☺ ☺ ☺

CONTENTS

LIST OF FIGURES

Table

List of Acronyms

This is a list of acronyms that have been used most commonly in this present study.

HA – Hearing Aid

NAL-NL1 – National Acoustics Laboratory – Non-linear 1

DSL[i/o] – Desired Sensation level [input/output]

LGOB – Loudness Growth at ½-octave bands

IHAFF – International Hearing Aid Fitting Forum

LTASS - Long Term Average Speech Spectrum

REUR – Real Ear Unaided response

REAR – Real Ear Aided Response

REIG – Real Ear Insertion Gain

MCL – Most Comfortable Level

WDRC – Wide Dynamic Range Compression

NAL-R - National Acoustics Laboratory-Revised

dB HL – Decibels Hearing Level

ANSI – American National Standards Institute

ISO – International Standards Organization

ANOVA – Analysis of Variance

Chapter 1

Introduction

Cochlear hearing loss in adult subjects can vary in terms of degree and configuration which creates a necessity for tailor made fitting of the hearing aid for every client. Most common practice in the clinics is to use a prescriptive procedure that takes care of approximate target amplification required for every individual. That is in prescriptive approaches amplification characteristics required were calculated based on hearing characteristics of the hearing-impaired individuals. In general prescriptive procedures were deceived from hearing characteristics and properties speech spectrum. The prescriptive methods were changed over the years due to advancement in technology, better understanding of hearing characteristics and other factors affecting hearing aid performance.

Prescriptive procedures for nonlinear hearing aids are based upon different underlying rationales. The idea behind these procedures is either to normalize loudness so that loudness recruitment can be compensated or to maximize speech intelligibility at various input levels (Dillon, 2001). Some of these fitting procedures use threshold and some others use supra threshold measurements as input data (Dillon, 2001). Threshold based procedures are mainly NAL-NL1 (National Acoustics Laboratory – Non-linear 1), (Dillon, 1999), FIG6 (Killion & Fikret-Pasa, 1993), and partly DSL [i/o] (Desired Sensation Level Input-Output, linear compression version), (Cornelisse, Seewald & Jamieson, 1995). Supra threshold procedures are LGOB (Allen et al., in 1990), IHAFF (Independent Hearing Aid Fitting Forum) (Cox, 1995) and partly DSL [i/o] (Desired Sensation Level Input-Output, curve linear compression version) (Cornelisse, Seewald & Jamieson, 1995).

Among the procedures described above, most commonly used procedure for prescribing hearing aids is NAL-NL1 and DSL [i/o] (Dillon, 2001).

The prescriptive formulae, threshold based or supra threshold based, give the first approximation of gain required. Practical clinical experiences with prescriptive methods show that the methods cannot eliminate the need for individual allowances and adjustments i.e., fine tuning of hearing aid (Dillon, 2001). However, one should bear in that fine tuning of gain settings in the hearing aids is performed on prescribed gain. The prescribed gain should be a good approximation to preferred gain, which reduces the trial and error done by the clinician and also saves time (Dillon, 2001).

According to a series of studies done by Keisder et al., (2001, 2005, 2006, 2007, 2008) they compared the gain prescribed by NAL-NL1 prescriptive formula and preferred by listeners with varies different degrees of hearing loss. They reported that, gain preferred by the adult experienced hearing aid users is lower by 6 dB on average in comparison to that prescribe by NAL-NL1. These studies suggest that prescriptive procedure has to be a good approximation to preferred gain on which fine tuning of the device according to individual needs will be performed. Similar results were also reported by Ching et al., (2010) for children, Zakis et al., (2007) in adult participants. All the above studies comparing preferred and prescribed gain were performed on western population. Little or no data is available on comparing preferred gain and prescriptive gain settings in experienced hearing impaired adults in Indian context.

Although, long term average speech spectrum (LTASS) may be similar across languages but frequency importance function (Studebaker & Sherbecoe, 1993) may be quite different for Indian languages which suggests different gain settings than that of western population. Further, general opinion among the clinicians in India is that, majority of the clients prefer different gain settings than that prescribed by NAL-NL1 and DSL [i/o]. Hence, it becomes all the more important to compare the prescribed and preferred gain settings in experienced hearing aid listeners.

Need for the study

As it has been noticed in the past, the gain settings provided by the prescriptive formulae isn't just sufficient to provide the best outcome during the initial fitting itself. For an optimal fitting solution to be achieved, fine tuning in addition to the prescribed formulae becomes all the more important. To satisfy the user at the first fitting itself, we will have to be aware of the changes that have to be brought about along with the prescribed formulae. Therefore, it becomes imperative on our part to know the deviations that occur based on the needs of the user and the degree of hearing loss. Hence, based on the afore mentioned data, it becomes all the more important to study the differences between the preferred gain settings and the most commonly used fitting formulae i.e., NAL-NL1 and DSL [i/o]. These deviations can be studied using various parameters like; 1) the overall gain at various input levels, 2) REIG data and 3) speech perception measures.

1. Need to study overall gain

As stated earlier, the output of the hearing aid varies according to the input. So the overall gain is the output minus input. By studying the gain at different input levels, it would help us to know the way the hearing aid functions at various input levels. This parameter has been commonly used by many researchers to compare preferred and prescribed gain by different formulae (Keidser et al., 2001, 2005, 2006, 2007, 2008 and; Ching et al., 2010; Moore et.al., 2001; Zakis et.al., 2005; Ching et.al., 1997). Majority of studies reported that gain prescribed by NAL-NL1 is louder or insufficient at least at one level (45 dB input, 80 dB input, or 65 dB input) for children (Ching et al., 2010) and in adults (Keidser et al., 2001, 2005, 2006, 2007, 2008). There were few studies to compare the DSL [i/o] in adult listeners with preferred gain (Ching et al., 2010). Hence, it is important to compare the overall gain at different input levels prescribed by different prescriptive formulae and preferred gain settings.

2. Need to study REIG data

Second parameter is to measure the REIG data. REIG provides the true gain in the ear canal. Aazh et al., (2007) have demonstrated that, the currently available programming software provides an inappropriate gain than that prescribed by the prescriptive procedures (Aazh et al., 2007; Swan and Gatehouse, 1995). This can only be identified and adjusted using REIG measures, hence making this an important tool while fitting the hearing aid. Further, to know at which frequencies, there is a difference between preferred and prescribed gain, this is needed. Hence it is a very important parameter that needs to be investigated.

3. Need to study speech perception

Many researchers have used this parameter to check for the differences in the gain prescribed in various conditions. Some have used continuous discourse with noise (Keidser et al., 2005) and a few others have used speech recognition threshold as a measure (Moore et al., 2001). They all demonstrated that scores were different between preferred and prescribed condition. Hence, it becomes an important tool to study the difference in perception because the main aim of a prescriptive formula is to give maximum emphasis on speech, which in turn can be evaluated using speech perception measures. To assess the differences in the prescriptive procedures and preferred gain procedures, overall gain, REIG measures, speech identification scores across the three conditions were considered.

Aim of the study

The present study was carried out with the aim to find out the difference between the outcomes of preferred gain settings and prescribed gain settings using NAL NL-1 and DSL [i/o] fittings strategies.

Objectives

- To compare overall gain between preferred gain settings, NAL-NL1, DSL[i/o] prescriptive formulae at various input levels (45 dB, 65 dB & 80 dB)
- To compare the differences in REIG scores across the three conditions at 65 dB input level
- To compare the Speech identification scores across the three conditions.

Chapter 2

REVIEW OF LITERATURE

Technological advancement, has led to substantial research in all areas including that of aural rehabilitation and surely, hearing aids are no exception. Complete digital technology is now available in various non linear hearing aids. The desired amplification requirements for hearing impaired individuals are met by using these non linear hearing aids, which are flexible in nature. As individuals with sensory-neural hearing loss experience an abnormal growth of loudness perception with the increase in input levels, these devices offer an excellent solution for their problem. Digital hearing aids provide relatively more amplification for soft sounds and less amplification for loud sounds without manipulation of the volume control switch manually.

Prescriptive selection procedures have had a long history and their references can be found even during 1930s. Knudsen and Jones (1935) proposed that the gain needed at each frequency was equal to the threshold loss at the same frequency minus a constant. This is also known as mirroring of the audiogram, because the shape of the gain frequency response equals the inverse of the shape of the hearing loss. The mirroring procedure follows a pattern such that there is a 1 dB increase in additional gain given to overcome every 1dB increase in hearing loss. But it can be deduced by the pattern that the gain prescribed maybe more than necessary at certain frequencies, where the hearing loss and the loudness growth will not be similar for all individuals. Hence, for all higher levels, the amount of gain would be excessive if all gain prescription methods follow mirroring procedure. Mirroring thus leads to excessive gain, especially for those frequencies with the greatest hearing loss (Dillon, 2001).

The next step in this regard was to provide required gain based on the person's most comfortable level (MCL) rather than on their thresholds. Watson and Knudsen (1940) suggested that speech should he amplified sufficiently to make speech energy audible and comfortable. Although their specific formula, incorporated MCL, but did not take into account the variation of speech energy across frequency. In mid-1940's, half gain rule was proposed based on the observation that people chose the required gain which is approximately half of their hearing loss. In fact, half gain rule and raising speech to MCL are both very similar. In cases of mild to moderate sensorineural hearing loss, the threshold of discomfort is little different from that in normal hearing individuals. As MCL is approximately half way between threshold of hearing and discomfort, every 2 dB increase in hearing loss requires MCL to be raised by 1dB. This gain is approximately half of the hearing loss.

But the primary aim is to raise speech to MCL, but the speech intensity across the frequency spectrum is not same, such as low frequency components are more intense than the high frequency sounds. Hence, half gain rule needs some modifications, like either increasing gain for high frequencies or by decreasing gain at low frequencies or both (Dillon 2001). Moreover, the half gain rule also needs to be modified for severe and profound hearing losses. When hearing thresholds are greater than 60 dB HL, discomfort thresholds are significantly above normal. So the relationship between threshold, MCL, and discomfort does not remain the same. In this case, MCL is elevated by more than half of the hearing threshold loss. Hence, the gain to be provided must be more than half of the hearing loss (Dillon, 2001).

With all the previous data, it is very clear that even more than 50 years ago, the basis for prescription for gain was based mainly on two auditory attributes, hearing threshold and supra-threshold loudness percept (such as MCL). The link between these is made clear in some procedures where threshold and discomfort levels are measured: but are used to estimate MCL by assuming that MCL bisects the person's dynamic range (Dillon 2001).

2.1 Prescriptive procedures

This complex and inter twining relationship between threshold and loudness perception provides the base for most current procedures for advanced non-linear hearing aids. So far, prescription procedures for non-linear devices can be broadly classified into two categories.

1. **Loudness Based procedures** : A few of them being Loudness Growth in Octave Bands (LGOB) (Allen, Hall, &Jeng, 1990), Independent Hearing Aid Fitting Forum (lHAFF) (Cox, 1995), ScalAdapt (Kiessling, Schubert & Arehut, 1996).
2. **Threshold Based procedures**: Some of them being National Acoustic Laboratory Non-Linear, version 1 (NAL-NL1) (Dillon, 1999), F1G6 (Killon & Fikret-Pasa, 1993), Desired Sensation Level (input/output) (DSL [i/o]) (Cornelisse, Seewald, &Jamiason, 1995)

Nonlinear prescription can be viewed as specifying the gain-frequency response for several levels of input. Both, average gain and frequency response vary with input level. Alternatively, this can be viewed as specifying input-output curve at many frequencies. However, it is totally impractical to prescribe a hearing aid solely based on prescriptive methods as evaluation of the end results, such as fine tuning of the device according to individual needs is essential in all cases (Dillon, 2001). The following section deals with the various prescriptive formulae.

Loudness growth in half-octave bands (LGOB)

LGOB aims to normalize loudness. Here, the client has to rate the loudness of narrow-band noises on a 7-point rating scale. The average level corresponding to each loudness category in a hearing impaired person is compared to levels needed in a normal hearing person. Now, for each input level, the gain needed to normalize loudness is found out and applied.

FIG6

This procedure specifies how much gain is required to normalize loudness, especially at medium and high-level input sounds. This is not based on individual measures of loudness but on hearing threshold. Rather, it uses loudness data averaged across a large population with similar degree of hearing loss. Gain is prescribed at input levels of 40, 65 & 95dB SPL and is interpolated for the rest. Generally, for low-level input sounds (40dB SPL), the basis for prescription of gain is that for mild-moderate degree of hearing loss patients should have aided thresholds 20dB above normal hearing threshold. For comfortable level (65dB SPL) input signals, the amount of gain prescribed for any degree of hearing loss is equal to the MCL of the normal hearing population. For high level (95 dB SPL) input signals, the gain prescribed is equal to the boost required to make it equally loud as in a normal hearing person (Dillon 2001).

CAMEQ

This procedure (Moore et al., 1999b) aims to place as much of the speech spectrum information as possible above absolute threshold for a given overall loudness. This is achieved by amplifying speech such that, on average, the loudness is similar for a frequency range between 500-5000Hz. The most specific goal is to make the loudness same in each critical band. This goal can be described as amplifying speech so as to give a flat loudness pattern across frequencies. This also aims to achieve equal across different input levels and achieve same overall loudness as normal for speech over a wide input levels.

CAMREST

This procedure (Moore et al., 2000) determines the gain needed to restore perception of loudness to normal for speech like stimuli. This not only attempts to restore overall loudness to normal but also makes the relative loudness across frequency bands the same as ‘normal’. This also aims at normalizing loudness for speech over a wide range of input levels.

In the current day technology, most hearing aids are non – linear, multichannel. They mostly use prescriptive procedures such as NAL NL – 1 and DSL [i/o]. The following section will describe these two formulae in detail.

NAL NL-1

The name NAL-NL1 stands for National Acoustics Labs, Non-linear, version 1 and was first described by Dillon in 1999. The underlying assumptions behind this procedure like its predecessors NAL-R and NAL-RP is to maximize speech intelligibility subject to the overall loudness of speech at any level being not more than perceived by a normal hearing person. The main objective of developing NAL-NL1 was to determine the gain for several input levels that would result in maximal effective audibility. This is neither based on loudness normalization nor equalization. However in this procedure the loudness of the signal is varied to such an extent where speech intelligibility is maximized (Dillon et al., 2001).

NAL NL-1 is based on two models: Loudness model (Moore and Glasberg, 1997) & Speech Intelligibility Index (SII), (ANSI, 1993). The only information required is the hearing thresholds and the speech spectrum levels input to the ear after amplification. One of the main criterions is that the loudness of an amplified speech should not be louder than that perceived by someone with normal hearing. If the lower levels result in higher SII, gain on the hearing aid will be reduced to achieve higher SII.

NAL NL-1 is based on a complex equation that specifies insertion gain at each standard 1/3 octave frequencies from 125Hz to 8000Hz. For speech input at any level, gain at each frequency was systematically varied with a high speed computer until the calculated speech intelligibility was maximized, but without the calculated loudness exceeding that loudness calculated for normal hearing people listening to speech at the same level. This procedure was repeated for many representative audiograms and the optimized gains for each audiogram, for each input level were found. As this was a very time consuming process, even for a single audiogram at a single input level, an equation was fitted to the complete set of optimized gains. This equation thus summarizes all the optimizations and can be applied to any audiogram. Alternately, the aid can be prescribed in terms of real ear aided gain (REAG). REAG is deduced from insertion gain by adding the adult average real ear unaided gain (REUG) to the insertion gain target (Dillon, 2001).

The NAL – nonlinear software program displays the results as either gain curves at different levels, or I/O curves at different frequencies. These curves can be for a 2 – cc coupler, an ear simulator, or the real ear. In case of real ear prescription, the gains can be either insertion gain or REAG. For multichannel hearing aids, crossover frequencies, compression thresholds, compression ratios and gains for 50, 65 and 80dB SPL input levels were also recommended by NAL-NL1 programming software.

Amplification requirements for people with mixed losses are fulfilled in two steps. First, by applying the gain formula to the sensorineural part of the person's hearing loss (i.e. the bone conduction thresholds) and then calculating the gain equivalent to 75% of the conductive part of the loss (i.e., the air bone gap) and then adding them (Dillon, 2001).

DSL [i/o]

This fitting strategy is just like its predecessor DSL and is based on loudness equalization or normalization. Loudness normalization means that sounds that appear soft to a normal hearing person should be audible soft, after amplification, to the hearing-impaired person. Similarly, sounds that are comfortable or loud, for the normal hearing person should be comfortable or loud, respectively, after amplification for the hearing aid user. There are basically two aspects of normalization. First, the overall loudness of sounds is normalized. This means for any input level and frequency, the sound would be equally loud for a normal hearing individual and to a hearing impaired person after amplification Second; the relative loudness of each frequency components of complex sounds will be preserved. By equalization, it means that all frequency bands of speech will be amplified sufficiently to produce equal loudness of speech.

The name DSL[i/o] stands for Desired Sensation Level [Input/Output] and was first described by Cornelisse, Seewald and Jamieson (Cornelisse, Seewald and Jamieson, 1995). DSL [i/o] method provides prescriptive targets for the fitting of wide-dynamic-range compression hearing aids. DSL [i/o]'s goals were to have loud sounds not exceeding the individual's uncomfortable listening level, make speech undistorted and audible across a wide range of input levels without discomfort, and to normalize loudness (Cornelisse et al., 1995). DSL [i/o] utilizes low-compression thresholds to increase audibility of softer speech sounds. The DSL [i/o] method has the goal of fitting "the acoustic region corresponding to the extended normal auditory dynamic range into hearing-impaired individual's residual auditory dynamic range" (Cornelisse et al., 1995). The method is based on 'complete' compensation for recruitment, which in turn means restoration of dynamic range to normal and complete restoration of audibility of speech sounds.

Comparison of different prescriptive procedures

In the following section, an attempt has been made to compare amongst the various prescriptive methods and preferred gain settings. It can be said that even though there are a lot of fitting strategies for non-linear hearing aids, it is very difficult to definitely ascribe any one of them as the best. Also, it is important to know which rationale works best when listening to a range of input levels that hearing aid users are exposed to in real life situations. Here is a brief summary regarding the few studies that have been conducted in this regard.

Byrne et al. (2001) has made an attempt to compare NAL-NLI with DSL(i/o), FIG6 and IHAFF for flat, reverse slope, moderately sloping and high-frequency hearing loss for a range of input levels i.e., 50, 65 and 80 dB SPL. Results showed that, NAL-NLI prescribes less low frequency gain for flat and upward sloping hearing loss, while it prescribes less high-frequency gain for moderately sloping and steeply sloping high frequency loss, when compared to other procedures. The relative differences in gain prescribed are different as expected as they are based on different principles. As already mentioned, NAL-NLI attempts to make the spectral balance in the speech signal, which is required to maximize calculated speech intelligibility. As it is a well known fact that low frequency parts of the signal contribute to the loudness of the signal than the high frequencies, NAL-NL1 gives low cut while prescribing gain, which is not so for other procedures. The other procedures attempt to normalize loudness at each frequency. NAL NL-1 procedure never attempts to produce a high sensation level at the frequencies with the greatest loss, because the ear's ability to extract information at those frequencies would have decreased. However, it is unclear that in spite of the fact that all three procedures have similar rationales, they prescribe different gain for various configurations of hearing loss. This may be because of the slight differences in their rationale and in the normative data they utilize (Dillon 2001).

Ching et al. (2010) compared the relative effectiveness of the NAL-NL1 and the DSL v.4.1 prescription procedures for children with mild to moderately severe hearing loss. 48 subjects were taken for this study and this study was being conducted simultaneously in Australia and Canada. Evaluations for this study included speech perception tests, loudness ratings, paired comparison judgements of intelligibility, and children's preferences and performances in real-world environments. This study was divided into various trial periods. During the first trial period, half of the participants received the NAL-NL1 and the other half the DSL v.4.1 prescription fitting. This was carried on for 8 weeks after which, each participant received the other prescription for the second trial period of another eight weeks. During the third and fourth trial periods, both prescriptions were put into separate programs in their respective hearing aids, using a remote control for access by the participants at all times. Each of the third and fourth trial periods were for duration of four weeks. At the end of each trial period, battery of tests was administered for assessment. Results indicated that the DSL v.4.1 procedure prescribed higher gain (0.5 to 4 kHz) than the NAL-NL1 prescription on average by about 10 dB. It was also noted that across trials 1 and 2, more negative comments about noise disturbance was associated with DSL v.4.1 than with NAL-NL1, and positive comments about loudness comfort was associated with NAL-NL1 than with DSL v.4.1. They also reported that across trials 3 and 4, more positive comments about listening to soft speech and speech from a distance or behind were associated with DSL v.4.1 than with NAL-NL1. The authors concluded that, the findings imply that the gain requirements of children in real-life situations are not met prescribed either by NAL-NL1 or the DSL v.4.1 prescription. Hence, to achieve optimal audibility of soft speech, children need more gain than what is prescribed by NAL-NL1 and to achieve listening comfort in noisy places, children need less gain than what is prescribed by DSL v.4.1.

Stelmachowicz et al. (1998) using Resound 2-channel fast acting WDRC hearing aid compared the gains for input levels of 50 and 80 dB SPL prescribed by DSL[i/o], FIG6 and a proprietary algorithm. They reported that DSL [i/o] procedure over-prescribed gain at 500, 2000 and 4000 Hz at both input levels. FIG6 under-prescribed gain for mild and moderate hearing losses, particularly at the 80 dB input level, but over prescribed gain for severe to profound losses. The manufacturer's algorithm provided a closer approximation to the gain actually used by the adults in this study. That is not too surprising, as the proprietary formula was a statistical summary of the gains actually used by wearers of precisely this type of hearing aid. It is however possible that the gains used by the subjects were influenced by the gains they were fitted with, which in turn were influenced by the proprietary fitting formula.

Humes et. at., (1999) compared a two-channel WDRC device prescribed using DSL [i/o] to a linear hearing aid prescribed using NAL-R. The WDRC instrument gave superior speech intelligibility, particularly at lower input levels and was preferred by 76% of the subjects in field trial. One possible interpretation is that DSL[i/o] prescribed a more appropriate gain-frequency response for mild-level inputs than did NAL-R. For high frequency sounds, both prescribed lesser than required because of the differences in the two prescription and the mean high-frequency gain achieved for the WDRC instrument was closer to NAL-R than to the DSL[i/o] prescription procedure.

Moore, et al., (2001) compared the effectiveness of the CAMEQ, CAMREST and DSL [i/o] fitting procedures in experienced hearing aid users fitted bilaterally. Immediately after fitting with a specific procedure and one week after fitting, the gains were adjusted by minimal amount necessary, if required .The same process was carried out for all the fitting procedures. On average, the gain adjustments were smaller for the CAMEQ followed by CAMREST and largest tor DSL[i/o]. The authors conclude that DSL [i/o] provide more high frequency gain than preferred by adult users. Overall, the CAMEQ and CAMREST procedures give more satisfactory initial fits than DSL [i/o] for experienced adults. But there is no mention if the subjects have used the same prescriptive formula previously.

In a similar study that involved experienced hearing aid users but fitted unilaterally, Alcantara et al., (2004) showed similar results as that of previous one. The authors commented that CAMEQ and CAMREST procedures provide a more initial fitting than DSL [i/o] even far unilaterally, experienced hearing aid wearers.

Also, comparisons with the previous study based on bilateral findings suggest that the gain preferences were found to be same for unilateral and bilateral fittings.

Zakis et al., (2007), conducted a study wherein they divided the hearing aid users into two groups. One group was given a hearing aid in which they could manipulate amplification parameters (compression threshold, gain prescribed below the compression threshold, compression ratio, and noise suppression strength) and the other group received hearing aids in which they could not manipulate any of the settings. They compared the preferences by the hearing aid users across various situations while using hearing aids. The results indicated that the subjects preferred the hearing aid in which the settings could be manipulated and it had been advised to use this in real-life listening situations by the clients.

Keidser and Grant (2001) compared two-channel WDRC hearing aids fitted according to NALNL - l and IHAFF protocol. Preferences under free field condition and in the laboratory condition both strongly favored NAL NL-1, particularly in presence of background noise. Speech identification scores in the laboratory also favored NAL-NL1, particularly in background noise. Keidser et al. (2008) conducted a study aimed at determining if gain adaptation occurs, and if it occurs, at which frequency bands do they occur, among new hearing aid (HA) users. Fifty new and 26 experienced HA users were taken for the study and were fitted with three listening programs (NAL-NL1 and NAL-NL1 with low- frequency and NAL-NL1 with high-frequency cuts) in the same hearing instrument family. Real-life gain preferences and comfortable loudness levels were measured at one month, four months and at 13 months post-fitting for the new HA users, and at one month post-fitting for the experienced HA users. The results indicated that new HA users prefer progressively less overall gain for average input levels than do experienced HA users with a similar degree of hearing loss. This was true even when the hearing loss increased. It was observed that the gain reduction from the NAL-NL1 prescription varies from -2 dB for those with a 4 frequency average (250Hz, 500Hz, 1000Hz & 2000Hz) hearing threshold of 25 dB HL down to-9 dB for those with a 4 frequency average (250Hz, 500Hz, 1000Hz & 2000Hz) hearing threshold 55 dB HL. It was also noted that for experienced hearing-aid users, NAL-NL1 generally overprescribed overall gain by about 3 dB for an input level of 65 dB SPL. And about half of both new and experienced hearing-aid users preferred a high-frequency cut in the gain-frequency response shape.

From figure 2.1, which is based on a series of studies done by Keisder et al., (2001, 2005, 2006, 2007), Dillon (2007) arrived at conclusions that the preferred gain with respect to NAL-NL1 at 65 dB input was just right for 49% of the hearing aid users; For 5 % of the population, gain prescribed by NAL-NL1 was not sufficient and the perception of sounds were soft but for the rest 46% the gain prescribed was more than 3 dB of what was required and the perception of sounds were loud.

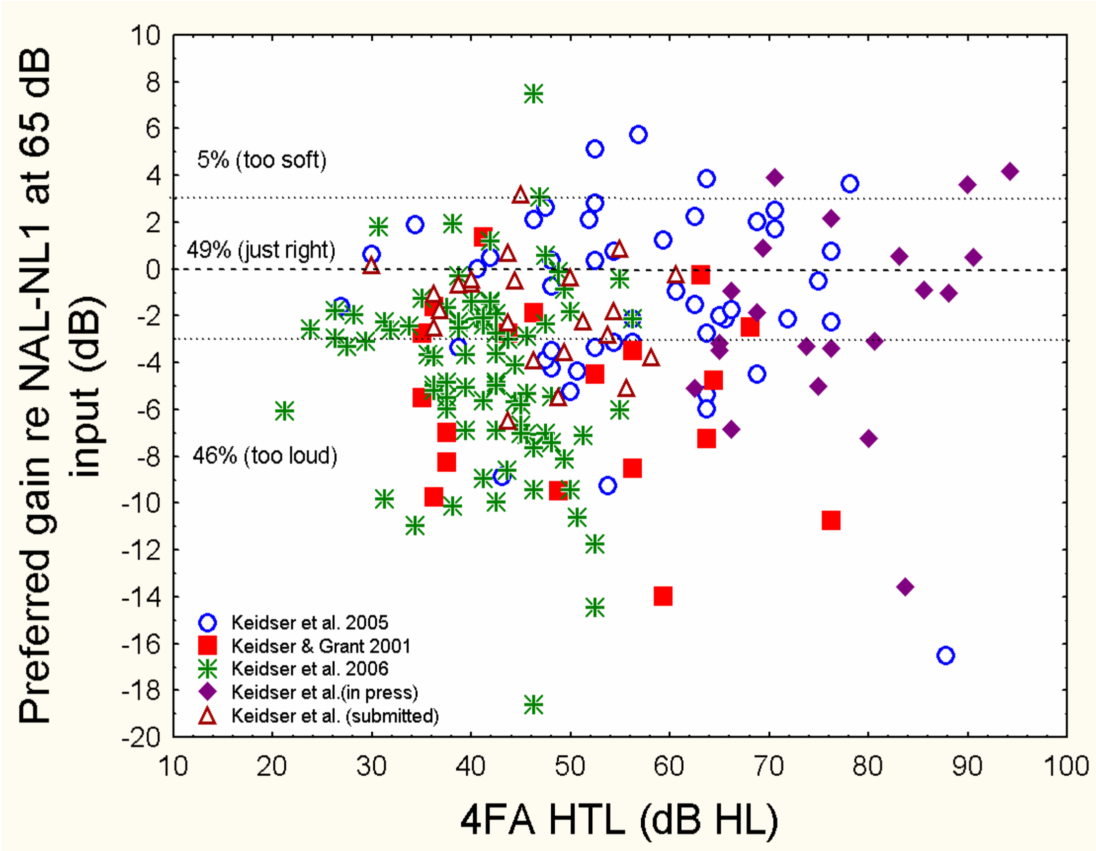

Figure 2.1: Preferred gain with respect to NAL-NL1 at 65 dB input (Dillon 2007).

This figure has been taken from a presentation by Dillon (2007) held at NE Conference, USA. This is available on their website.

In most of the earlier mentioned studies, the outcome measures are measured via many parameters and the most common amongst them is REIG. Many researchers base their results on this important tool. As stated earlier, REIG can be a very important tool to check if the gain prescribed in the hearing aid is accurate and the necessary changes that have to be made to achieve the target.

In a study conducted by Swan & Gatehouse (1995), to check if the real ear gain closely matches the prescribed gain and they found out that 57% of the subjects failed to come within 10 dB of the target gain at one or more frequencies between 250 Hz to 3 kHz. After appropriate changes 85% achieved a satisfactory gain.

Aazh, Hashir Moore & Brian (2007) conducted a similar study with the main aims of (1) determining whether routine real ear insertion gain (REIG) measurement is necessary in fitting digital hearing aids; and (2) assessing the extent to which modifying the frequency-gain response of an aid can lead to better matches to the target in cases where the target gain was not initially achieved. The target formula was selected as NAL-NL1 in the programming software of four types of digital hearing aids. REIG measurements on 42 ears showed that 64% of cases failed to come within ±10 dB of the target at one or more of the following frequencies: 250 Hz, 500Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz and 4 kHz. After adjusting the frequency-gain response of the aids, based on the REIG results, 83% of cases came within ±10 dB of the target. The results indicate that REIG measurements can and should be used to achieve more accurate fittings but that accurate adjustments are difficult with some aids. This study clearly states the need to make use of REIG.

Therefore, from the above studies we can clearly infer that most of the times, there is a discrepancy between the prescribed gain and the preferred gain settings. This discrepancy is seen mostly due to the programming software and also due to the fact that gain prescribed is not favorable to the participant's needs & modification of required might be required. This discrepancy is seen in speech perception studies as well. The most appropriate way to check for these discrepancies is to use gain at different input levels and REIG measures as it has been noted that there could be discrepancies in the output when compared with the target.

Chapter 3

METHOD

Participants

Ten (10 ears) participants, having sensory-neural hearing loss who had been clinically diagnosed as having cochlear hearing loss at Department of Audiology, All India Institute of Speech and Hearing, Mysore participated in the present study. All the participants were regular hearing aid users; the minimum duration of hearing aid use being more than one year. The age of the participants ranged from 30-75 years with the mean age of 64 years. All listeners were native speakers of Kannada (A Dravidian language spoken in a southern state of India). Pure tone average ranged from 30 to 91.6 dB HL. It was ascertained from a structured interview that none of these participants had any history of neurologic or otologic disorders. The demographic and audiological data of the participants, which includes degree of hearing loss, speech identification scores, hearing aid being used and the duration of hearing aid use, is provided in Table 3.1. The pure-tone thresholds at octave frequencies of each participant have been provided in Figure 3.1.

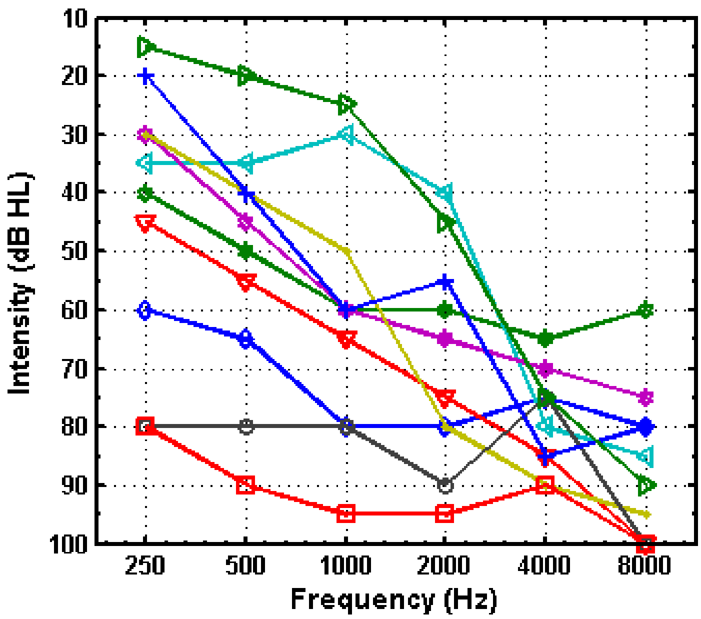

Figure 3.1: Pure-tone thresholds as a function of frequency for all the participants.

Table 3.1: *Demographic and Audiological data of the participants with cochlear hearing loss*

S.I. No.	Age/Sex	Ear	Pure Tone Average	Speech Identification score	Hearing aid model	Duration of HA use
1	59/M	Right	75	72%	Figaro 2P	24 months
2	59/M	Left	56.6	92%	Figaro 2P	22 months
3	69/M	Left	65	76%	Figaro 2P	19 months
4	71/M	Left	35	84%	Figaro 2P	14 months
5	63/M	Left	56.6	76%	Figaro 4P	16 months
6	71/M	Right	56.6	68%	Figaro 4P	19 months
7	73/M	Right	83.3	60%	Eclipse 2SP	21 months
8	71/M	Right	51.6	72%	Eclipse 2SP	17 months
9	75/M	Right	30	88%	Eclipse 2SP	21 months
10	32/M	Right	91.6	Nil	Eclipse 2SP	22 months

Pre-testing procedure

On otoscopic examination, all participants had ear canals that were free from cerumen, debris or foreign body. This was followed by estimating audiometric thresholds for Air Conduction at 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz and 8000Hz and Bone Conduction at 250Hz, 500Hz, 1000Hz, 2000Hz and 4000Hz using Modified Hughson & Westlake procedure (Carhart and Jerger, 1959). The thresholds obtained, were compared with pure-tone thresholds obtained during initial hearing aid fitting. None of the participants had a shift in their threshold by more than 10 dB in air conduction or bone conduction mode in any of the frequencies. All the subjects had normal middle ear functioning and the same was confirmed by testing with GSI-Tympstar Immittance meter.

Test Environment

All the testing was conducted in an air conditioned, acoustically treated double room set up. The ambient noise levels inside the test room were within permissible limits (ANSI S3.1 1999).

Instrumentation

1. Orbiter OB-922 (Madsen Electronics, Denmark), two channel diagnostic audiometer calibrated (ISO 389) with supra aural head phones (Telephonics TDH-39), bone vibrator (Radio ear B-71) were used to assess the pure-tone threshold.
2. Hearing aid type: Three types of hearing aids were used in the present study namely Electone Eclipse 2 SP, Figaro 2P and Figaro 4P. These hearing aids incorporate features such as two-channel (maximum 4 in Figaro 4P), adjustable cross-over frequency and dual / syllabic compression. The compression ratios are set by the software according to the specified prescriptive procedure. These particular models were selected because they are most commonly used by most of the participants.
3. FONIX 7000 hearing aid analyzer was used to check the electro-acoustic characteristics of the hearing aid and also the real ear aided gain (REAG) measurements.
4. Hardware and software to program the hearing aids. A personal computer connected to HIPRO for programming the hearing aid. The NOAH software (version 3.1.2) and the hearing aid specific software (Electone) along with Win CHAP (Computerized Hearing Aid Program for windows, version 2.82) were installed in this computer.

Procedure

1. **Speech Identification Scores**

Speech Identification scores were assessed in Kannada language. This was assessed using live voice presentation. Stimuli used were Yathiraj and Vijayalakshmi (2005) word list and it was scored out of 25 words and by finding out the percentage for the correct responses. This test material consists of 4 word lists of 25 words each. This test material was used in 4 different conditions, which will be explained in detail in the next section and for each of these conditions, different word list was used. Stimuli were presented through the loud speakers placed at 0 ° azimuth at a distance of 1 meter.

2. **Real Ear Measurements**

a. ***Real ear unaided response (REUR)***

This was measured for the subjects without wearing the hearing aid using FONIX 7000 hearing aid analyzer by using Digispeech as the stimuli at 65dBSPL as the input. The loudspeaker was kept at a distance of 12 inches and at 45 degree to the pinna (as specified in the FONIX 7000 user manual). A probe microphone was placed inside the subject's ear at a distance equal to the length of ear mould plus 5 mm. Before the stimulus was presented, leveling of the stimulus was done. The stimulus was presented and the output was represented in the form of a graph on screen and once the graph onscreen was stabilized for more than 10 seconds, the input was stopped. Then, the graph was converted to real ear unaided scores and the values were noted down.

b. Real ear aided response (REAR)

The subject's hearing aid was connected to the HIPRO using the programming cable and the HIPRO was connected to the computer. Once connected, the gain and program settings in the hearing aid, under all 3 conditions, i.e., subject's preferred settings, NAL-NL 1, DSL [i/o] (version 4.1) were noted.

Real measures were performed for, preferred, NAL-NL 1 and DSL[i/o] gain settings in all the subjects using the FONIX 7000 hearing aid analyzer by using digispeech as the stimuli at 65 dB SPL as the input. The loudspeaker was kept at a distance of 12 inches and at 45 degree to the pinna (as specified in the FONIX 7000 user manual). A probe microphone was placed inside the subject's ear at a distance equal to the length of ear mould plus 5 mm. Before the stimulus was presented, leveling of the stimulus was done. The stimulus was presented and the output was represented in the form of a graph on screen and once the graph onscreen was stabilized for more than 10 seconds, the input was stopped. Then, the graph was converted to real ear aided scores and the values were noted down.

The gain at three input levels (45 dB, 65 dB, and 80 dB) was noted from the software program and REAG was obtained from real ear measures across all the aided conditions were tabulated and subjected to analysis and the results obtained have been discussed in the next section.

Chapter 4

Results and Discussion

The present study was carried out with the aim to find out the difference between the outcomes of preferred gain settings and prescribed gain settings using NAL NL-1 and DSL [i/o] fittings strategies. The data of overall gain at three input levels and REIG were collected and tabulated. The tabulated data was further subjected to data analysis. Statistical analyses were done using SPSS Statistics Package (version 17).

The following statistical analysis were carried out on the data

- Descriptive statistics were carried out to find out the mean and standard deviations in the data
- Friedman's ANOVA was carried out to find out if the mean difference is significant in the three conditions at all the three input levels separately
- Wilcoxon signed rank test was administered to compare across the three conditions.
- One-way ANOVA (Analysis of Variance) was carried out to find out if there was any significant difference between the groups with the level of significance being 0.05
- Bonferroni post-hoc analysis was done to estimate which groups had a significant difference with the level of significance being 0.05.

Comparison of Gain at three input levels

Figure 4.1, shows the gain at three input levels i.e., 45dB (soft sound input), 65dB (overall gain), 80dB (loud sound input) for three conditions. For 45 dB & 80 dB input levels data was available for only 6 subjects. As it can be noted from the Figure 4.1, the gain, overall is higher for preferred condition compared to NAL-NL1 and DSL[i/o] at all input levels. The difference is higher at 65 dB and 80 dB input level compared to 45 dB input level. In addition, DSL[i/o] provides slightly higher gain at all the input put levels compared to NAL-NL1.

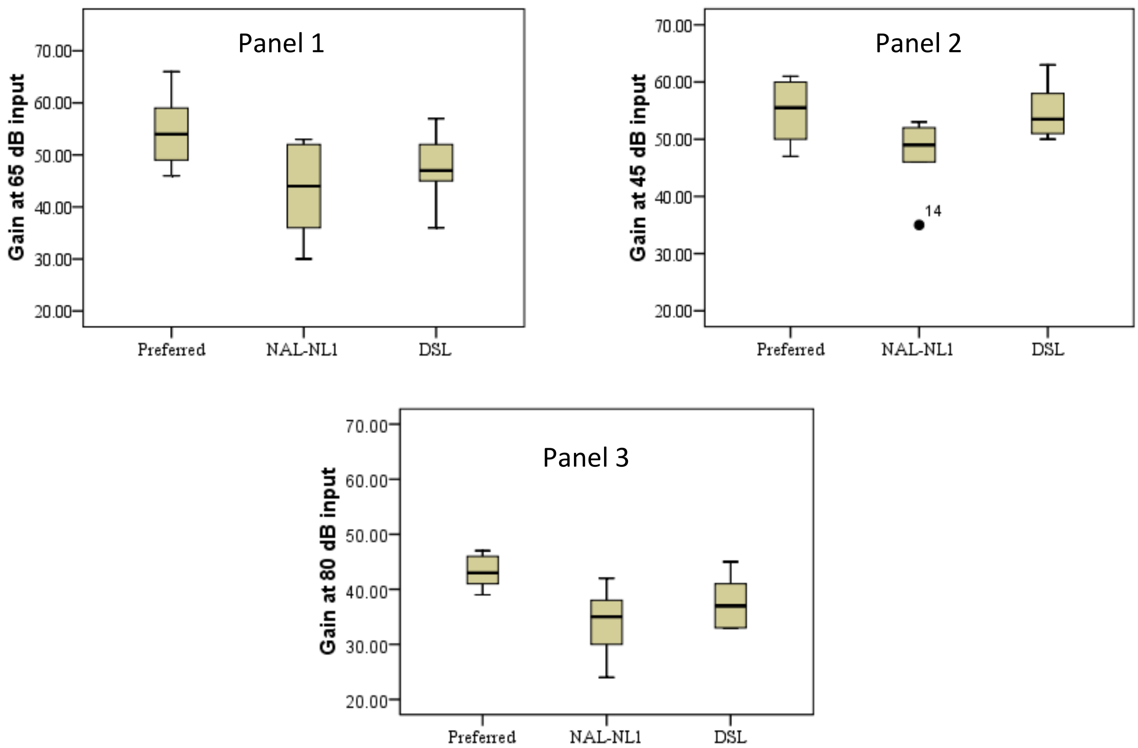

Figure 4.1: Gain at three input levels 65 dB (Panel 1), 45 dB (Panel 2) and 80 dB (Panel 3).

Friedman's ANOVA was carried out to find out if the mean difference is significant in the three conditions at all the three input levels separately. For all the Friedman's ANOVA analysis a Bonferroni correction was applied and so all the effects are reported at 0.016 level. At 65 dB input level, analysis revealed that mean difference is significant across three conditions for overall gain ($\chi^2_{(2)}$ = 12.1, p<0.001). This is followed by Wilcoxon signed rank test to compare across conditions. Results revealed that there was a significant difference between preferred and NAL-NL1 (Z=2.6, p< 0.01), DSL[i/o] and NAL-NL1 (Z =2.56, p< 0.01), whereas, there was no significant difference between preferred and DSL[i/o] (Z=1.5, p=0.144). Similar analysis was carried out for 45 dB input ($\chi^2_{(2)}$ = 5.3, p= 0.069) and 80 dB input condition ($\chi^2_{(2)}$ = 8.2, p=0.017*) and results revealed that there was no significant difference across conditions.

Results of present study clearly show that majority of the participants needed a gain of about 10 dB higher than NAL-NL1 and about 5 dB higher than DSL [i/o]. These results clearly demonstrates that gain needed in the Indian subjects is higher than that prescribed by NAL-NL1 and DSL[i/o] for 65 dB input level. These results are in agreement with clinical observation made by majority of the clinicians. The precise reason for needing a higher gain is not known. Probable reasons for higher gain requirement in the present study is as follows; first, for the western population, Keidser et al., (2001, 2005, 2006, 2007, 2008) reported that preferred gain is lesser by 6 dB than that prescribed by NAL-NL1 in 46% of subjects, gain prescribed and preferred was similar in 49% of subjects and a only 5 % of subjects need more than NAL-NL1, this amounts to 3-8 dB. Probably, the subjects taken in the present study fall in the 5% range. Another reason could be that, as Studebaker & Sherbecoe (1993) reported that frequency importance functions vary widely across the languages and hearing aid prescriptive formulae were derived from the frequency importance

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* Note: By applying the Bonferroni correction, p=0.017 is not significant as significant value is less than 0.016.

function. Probably, the frequency importance functions for Indian languages are different which would have led to this difference.

Comparison of REIG

Using the REUR data and REAR data, the REIG (Real Ear Insertion Gain) data was calculated for each subject at each frequency for all the three conditions. This was calculated using the formula described by Dillon (2001). REIG values were calculated only at octave and mid octave frequencies. The individual REUR, REAR scores for all the subjects at each frequency in all three conditions has been given in the appendix.

Real Ear Insertion gain (REIG) = REAG – REUG

REAG =Real ear aided gain, REUG = Real ear unaided gain

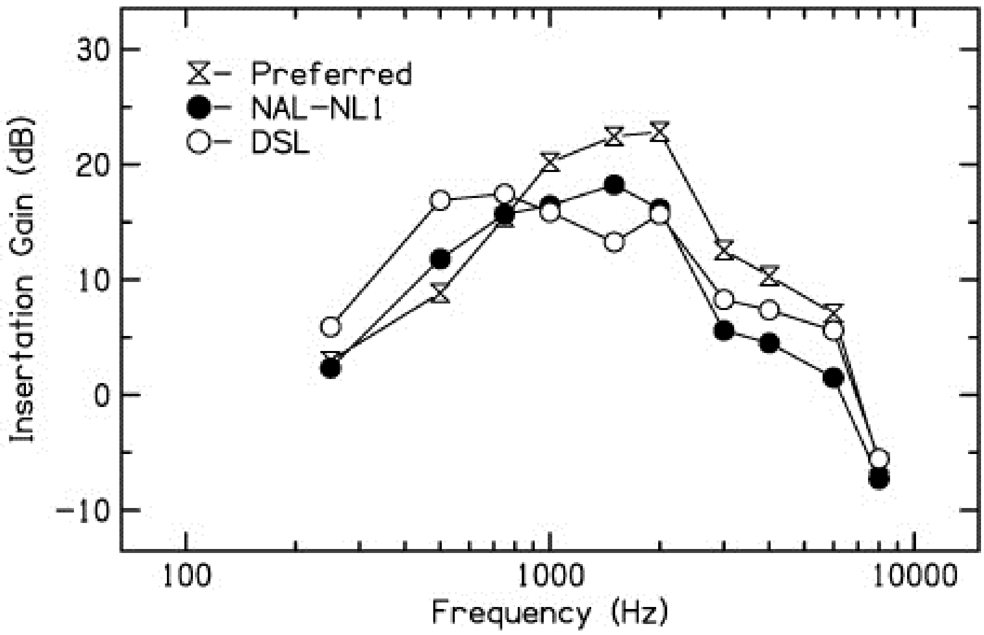

Figure 4.2: REIG values across Frequency for all three conditions.

Figure 4.2 represents the mean values of the REIG scores across frequency for all the three conditions at 65 dB SPL input signal. As it can be seen from the figure, there is a difference in the mean value across frequency in the three conditions. At the low frequency region, till about 800 Hz, REIG values of DSL [i/o] condition are greater than preferred condition and NAL-NL1. In the same region NAL-NL1 is slightly higher than preferred condition. At mid and high frequencies, REIG scores for the preferred condition were greater than NAL-NL1 and DSL[i/o] condition. At the high frequency region, DSL is also higher than NAL-NL1 condition. At the extreme high frequency region, the mean scores have dipped in all the three conditions because the frequency response of the hearing aid is limited up to 4000 Hz to 5000 Hz.

One-way ANOVA was carried out to find out if the mean difference of REIG scores is significant in the three conditions at all the frequencies. The data of 8 kHz was not considered in the analysis. The analysis revealed that there was a significant difference between the conditions at 3000Hz ($F_{(2,490)} = 5.75$, $p<0.05$), 4000Hz ($F_{(2,810)} = 12.20$, $p<0.05$), 6000Hz ($F_{(2,862)} =5.53$, $p<0.05$) input frequency. Post-hoc Bonferroni analysis showed that there was a significant difference between preferred and NAL-NL1 at 3000Hz, 4000Hz, & 6000Hz and significant difference between preferred and DSL at 3000Hz, 4000Hz & 6000Hz input frequency.

Results of the REIG clearly demonstrate, for the Indian population, higher gain is required at mid to higher frequencies. Although, the mean data is different, it did not reach significance at mid frequencies (1 kHz and 2 kHz); this is may be due to more variation noted in the data. Studebaker and Sherbecoe, (1993) has reported that frequency importance functions vary widely across the languages and hearing aid gain prescriptions were derived from the frequency importance function. Probably, the band importance function was different for mid and high frequency, which is why they needed a higher gain at mid and high frequency and not at low frequency. One more reason could be that the differences maybe because of the fine-tuning changes. As the subjects selected had undergone fine-tuning at regular intervals, it may be possible that the changes were mostly required at high frequencies in these populations. Similar results have been reported by Aazh, Hashir, Moore & Brian, 2007.

Comparison of Aided Speech Identification scores

Comparison of speech identification scores (SIS) was done. The mean scores for preferred condition were 75.5 % (6.46); for NAL-NL1, the mean scores were 64% (11.31) and the mean scores for DSL [i/o] was 61.33 % (11.45). By this analysis we can infer that the speech perception at the preferred condition was the best followed by NAL-NL1 and DSL [i/o]. One-way ANOVA was carried out to check if there was any significance across the three conditions. One-way ANOVA results revealed that there was a statistical significant difference between the three conditions ($F_{(2,514)}$ = 5.18, $p<0.05$). Post-hoc Bonferroni analysis showed that there was a significant difference between preferred and DSL [i/o] and no difference between preferred and NAL-NL1. Although, statistically there was no significant difference between preferred and NAL-NL1 condition, mean scores were higher by 10% in preferred than NAL-NL1. Mean scores did not reach significance between NAL-NL1 and preferred due to large SD (i.e., 11.5) noticed in the NAL-NL1 scores. The speech perception scores further supports that gain settings in the preferred gain condition is quite different from the gain settings prescribed by NAL-NL1 and DSL [i/o].

Overall, the results demonstrate that the subjects participated in the present study needed a higher gain than NAL-NL1 and DSL[i/o] by at least 10 dB at 65 dB input. In addition, more gain is required at higher frequencies than at lower frequencies. However, these results have to be interpreted with caution because, the present study did not control for gender, degree of hearing loss, age and the number of subjects taken up for the study were less. Hence, further studies are needed in this direction to cross-verify the results of the present study.

Chapter 5

Summary and Conclusion

The present study was carried out to compare the outcome measures between preferred gain settings and prescribed gain settings in experienced hearing aid users. The formulae that were taken for comparison were NAL-NL1 and DSL [i/o] (version 4.1) as these are the most commonly used prescriptive formulae across the world. Ten (10 ears) participants, having sensory-neural hearing loss participated in the present study. All the participants were regular hearing aid users; the minimum duration of hearing aid use being more than one year. The age of the participants ranged from 30-75 years with the mean age of 64 years. All listeners were native speakers of Kannada (a Dravidian language spoken in a southern state of India). Pure tone average ranged from 30 to 91.6 dB HL. Three types of hearing aids were used in the present study namely Electone Eclipse 2 SP, Figaro 2P and Figaro 4P.

For all these participants, Speech Identification Score (SIS) was found out, both in unaided and aided conditions. After this, REUR and REAR were measured at an input level of 65 dB SPL. REAR was measured under three conditions, i.e., preferred, NAL-NL1 & DSL [i/o], after programming the hearing aid, separately and the aided values were noted down. Along with this, the overall gain (65 dB input), gain for soft sounds (45 dB SPL) and gain for loud sounds (80 dB SPL) were also noted down.

The main findings of the present study were

- The overall gain is higher for preferred condition compared to NAL-NL1 and DSL[i/o] at all input levels. In addition, DSL[i/o] provides slightly higher gain at all the input put levels compared to NAL-NL1.
- The difference is higher at 65 dB input condition and at 80 dB input condition compared to 45 dB input level.
- Comparison of REIG scores revealed that there was a statistically significant difference between preferred and NAL-NL1 at 3000Hz, 4000Hz, & 6000Hz and significant difference between preferred and DSL at 3000Hz, 4000Hz & 6000Hz input frequency.
- Comparison of a SIS showed that there was a significant difference between preferred and DSL [i/o] and no difference between preferred and NAL-NL1

Finally, it can be inferred from the results of the present study that for the Indian population, higher gain is required at mid to higher frequencies, compared to western population. This study supports the notion that better speech perception scores are achieved in conditions which have favorable gain settings. This study also reflects on the importance of fine-tuning of hearing aids based on participant's preference because the results of this present study was based on the fine tuning changes made based on subjective preference and it was mostly in the mid to high frequencies which was consistent across all the participants.

Future implications

- The comparisons in the present study were done based on the data of ten subjects, only. Probably the study can be carried on further by comparing it using more no of participants.
- This same study can be carried out, based on degree of hearing losses.
- If a definite trend is observed across the population, then it can be safely assumed that the differences are mostly seen in Indian population and this data can be used to develop a new prescriptive formula for specifically Indian population.

REFERENCES

Aazh, H., & Moore, B. C. J. (2007). The Value of Routine Real Ear Measurement of the Gain of Digital Hearing Aids. *Journal of American Academy of Audiology,* 18, 653–664.

Alacantara, J. I., Moore, B. C. J.,& Marriage, J. I. (2004). Comparison of three procedures for initial fitting of compression hearing aids. II. Experienced users, fitted unilaterally. *International Journal of Audiology.* 43 (1), 3-14.

Allen. J.B., Hall. J. & Jeng. P. (1990). Loudness growth in ½-octave bands (LGOB) – a procedure for assessment of loudness. *Journal of Acoustical Society of America*, 88(2), 745-753.

American National Standards Institute. (1999). Maximum permissible ambient noise for audiometric test rooms. ANSI S3.1 – 1999 (R 2003). New York : ANSI, Inc.

Berger.K.W., & Harberg.E.N (1982). Gain usage based on hearing aid experience and subject age. *Ear and Hearing*, 3 (4), 235-237.

Byrne, Dillon.H., Ching.T., Katsch,R.,&Keidser,G., (2001). NAL-NL1 procedure for fitting non-linear hearing aids:characterstics and comparison with other procedures. *Journal of American Academy of Audiology*. *12* (1), 37-51.

Carhart, R., & Jerger, J.F. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders*, 24, 330-345

Ching T.Y.C., Scollie S.D., Dillon H., Seewald R., (2010).A cross-over, double-blind comparison of the NAL-NL1 and the DSL v4.1 prescriptions for children with mild to moderately severehearing loss. *International Journal of Audiology*, 49, S01–S15.

Cornelisse. L., Seewald. R. & Jamieson. D. (1995). The input/output formula: a thoeritical approach to the fitting of personal amplification devices. *Journal of Acoustical Society of America,* 97(3), 1854-1864.

Cox. R. (1995). Using loudness data for hearing aid selection: The IHAFF approach. *Ear and Hearing*, 48(2), 10, 39-44.

Dillon, H. (2001). Hearing aids. Turramurra: Boomerang press.

Dillon, H.(1999). NAL-NL1: A new prescriptive fitting procedure for non-linear hearing aids. *The Hearing Journal*. 52(4), 10-16.

Humes, L.E., Christensen, L. (1999). Comparison of the aided performance and benefit provided by a linear and a two-channel wide dynamic range compression hearing aid.*Journal of Speech Language & Hearing Research*, 42 (1), 65-79.

International Standards Organisation. (1994a). Acoustics : Reference Zero for the Calibration of Audiometric Equipment. Part 2: Reference Equivalent Threshold Sound Pressure Level for Pure Tones and Supra-aural ear phones. ISO : 389-1. 1998.

Kasauri,M.(2006). Effect of preffered gain and prescribed gain on speech perception in noise- A validation of prescriptive formulae. Unpublished Masters dissertation. University of Mysore, Mysore.

Keidser, G., & Grant, F. (2001). Comparing loudness normalization (IHAFF) with speech intelligibility maximization (NAL NL-1) when implemented in a two-channel device. *Ear and Hearing*.22(6), 501-515.

Keidser, G., Brew, C., Brewer, S., Dillon, H., Storey. L., & Grant, F. (2005). The preferred response slopes and two-channel compression ratios in twenty listening conditions1 by hearing-impaired and normal-hearing listeners and their relationship to the acoustic input. *International Journal of Audiology*, 44, 656- 670.

Keidser, G., & Dillon, H. (2006). What’s new in prescriptive fittings Down Under? In Palmer, C.V., & Seewald, R. (Eds.), *Hearing Care for Adults.* pp. 133-142. Phonak AG, Stafa, Switzerland.

Keidser, G., Dillon, H., Dyrlund, O., Carter, L. & Hartley, D. (2007). Preferred low- and high-frequency compression ratios among hearing aid users with moderately severe to profound hearing loss. *Journal of American Academy of Audiology* 18(1), 17-33.

Keidser, G., O’Brien, A., Carter, L., McLelland, M., Yeend, I. (2008). Variation in preferred gain with experience for hearing aid users. *International Journal of Audiology*. 47(10), 621-635.

Kiessling. J., & Steffens, T. (1996). Adaptive fitting of hearing instruments by category loudness scaling (ScalAdapt). *Scandinavian Audiology.* 25(3). 153-160.

Killion. M.C. & Fikret-Pasa. S. (1993). The 3 types of sensorineural hearing loss: loudness and intelligibility considerations. *The Hearing Journal,* 46(11), 31-36

Knudsen, V., & Jones, A. (1935). Prescribing hearing aid performance. In H. Dillon (Eds.), *Hearing Aids*(pp. 236-280). Turramurra: Boomerang press.

Leijon,A., Lildkvist,A., Ringdsah,A., & Israelsson,B. (1990). Preferred hearing aid gain in everyday use after prescriptive fitting. *Ear and Hearing.* 11(4), 299-305.

Marriage, J., Moore, B.C.J., &Alcantara, J.I. (2004). Comparison of three procedures for initial fitting of compression hearing aids. III. Inexperienced versus experienced users. *International journal of Audiology,* 43 (4), 198-210.

Moore, B.C.J., & Glasberg, B.R. (1997). A model of loudness perception applied to cochlear hearing loss. *Auditory Neuroscience.* 3, 289-311.

Moore, B.C.J., Glasberg, B.R., & Stone, M.A. (1999b). Use of a loudness model for hearing aid fitting. III. A general method for deriving initial fittings for hearing aids with multi-channel compression. *British Journal of Audiology.* 33, 157-170.

Moore, B.C.J. (2000). Use of a loudness model for hearing aid fitting. IV. Fitting hearing aids with multi-channel compression so as to restore 'normal' loudness for speech at different levels. *British Journal of Audiology.* 34, 165-177.

Moore, B.C.J., Alcantara, J.I. & Marriage, J.,(2001). Comparison of three procedures for initial fitting of compression hearing aids. I. Experienced users, fitted bilaterally. *British journal of Audiology,* 35 (6), 339-353.

Sehgal,A. (2005). A comparative study of proprietive and generic prescriptive procedures for non-linear hearing aids. Unpublished Masters dissertation. University of Mysore, Mysore.

Smeds.k., 2004. Is normal or less than overall loudness preferred by first- time hearing aid users?. *Ear and Hearing.*, 25, 159-172

Stelmachowicz, P.G., Dalzell, S. (1998). A comparison of threshold based fitting strategies for nonlinear hearing aids. *Ear and Hearing*, 19, 131-138

Studebaker, G. A., & Sherbecoe, R. L. (1993). Frequency-importance functions for speech recognition. In G. A. Studebaker & I. Hochberg (eds.), *Acoustical factors affecting hearing aid performance* (2nd ed., pp. 185-204). Boston: Allyn and Bacon.

Swan IR, Gatehouse S. (1995). The value of routine in the-ear measurement of hearing aid gain. *British Journal of Audiology* 29:271–277.

The Pediatric Working Group of the Conference on Amplification for childern With Auditory Deficits. (1996). Amplification for infants and children with hearing loss. *American Journal of Audiology.* 5, 53-68.

Watson, N., & Knudsen, V. (1940). Selective amplification in hearing aids. *Journal of Acoustical Society of America*, 11. 406-409.

www.nal.gov.au/pdf/NL2-etc-NE-conf-Dillon-download.pdf

Yathiraj, A., & Vijayalakshmi. (2005). Auditory memory test. Test developed at the Department of Audiology, All India Institute of Speech and Hearing, Mysore.

Zakis J.A., McDermott H.J. & Dillon H. (2007).The design and evaluation of a hearing aid with trainable amplification parameters. *Ear and Hearing*, 28(6), 812–830.

Appendix

Here are the REUR scores of all the subjects.

200 Hz	500 Hz	800 Hz	1000 Hz	1500 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
53.4	57.7	56	54.9	51.3	51.4	65.1	64.6	50.7	43.1
54.5	54.5	53.5	53.3	51.1	56.2	59.5	55.6	36.3	43.1
55.1	55.2	53.3	52.9	57	60.2	62.4	66.5	39.7	42.1
54.9	54.9	53.3	52.3	55	56.6	62.6	55.4	50.5	44.2
54.7	55.2	53.9	53.3	56.4	57.6	69.1	69.4	40.5	39.5
55	55.5	53.5	53.4	54.8	57.9	64.1	60.3	51.5	43.9
54.7	55.3	53	51.4	50.8	53.1	61.1	61.1	45.3	34.1
54.9	54.5	54.8	53.5	55	59.1	59.4	56.8	41.8	34.4
55.8	56.1	54	52	57.9	59.7	57.6	53.6	42.2	52.6
55.8	56.7	53.6	49.6	55.8	55.2	53.8	49.6	43.4	59.9

Here are the REAR scores of all the subjects under preferred condition.

200Hz	500 Hz	800 Hz	1000 Hz	1500 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
59.4	74.4	81.1	84.7	81.9	91.5	75.5	72.3	56.6	36.1
54.2	56.8	58	53.1	57.7	59.7	63.6	66.2	55.6	44.3
53.3	66.2	70.9	80.1	88.6	92.4	80.3	75	71.1	47
53.5	63.9	57.1	62.4	62	72.2	71.1	69.8	78.8	42.6
54.5	75.2	81.7	83.2	84.5	82.3	82.9	80.9	62.7	47.2
54	66	70.2	67.5	67.4	70.5	71.8	77.3	62.1	27.5
67.7	84.7	90.4	87.5	93.5	103.4	94	91.3	54.9	37.8
59.1	70.7	76.2	75.4	77.4	83.7	83.3	82.9	48.1	27.4
45.3	57.6	63.9	61.9	77.3	84.7	80.8	83	49.3	32.4
87.5	98.7	103.4	102.8	99.2	99	87	77.3	43.6	35.8

Here are the REAR scores of all the subjects under NAL-NL1 condition.

200 Hz	500 Hz	800 Hz	1000 Hz	1500 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
59	75.2	77.2	75	70	82.2	69.7	61.9	51.2	27.6
55	55.7	53.1	54.4	57	57	55.2	60.1	50.6	39.9
55.3	63.4	72.9	79.3	83.9	85.4	69.7	65.3	59	36.3
53.4	57.3	52.2	56.4	55.4	58.9	53.4	54.3	55	40
54.3	63.1	66.9	68.8	67.8	67.3	66.2	62.7	50.4	23.2
53.8	63.7	66.8	67.4	67.5	70.2	76	73.2	62.5	30.7
66.3	81.8	85.5	80.3	82.1	88.3	74	71.8	35.8	27.2
54.3	64.5	68.6	67.5	66.5	70.4	68.8	67.4	33.7	20.1
46.8	60.8	60.3	51.2	57.4	67.3	65.6	58.9	29.5	20.8
74	88.1	92.2	90.7	81.9	81.4	72	62.4	29.2	28.3

Here are the REAR scores of all the subjects under DSL[i/o] condition.

200 Hz	500 Hz	800 Hz	1000 Hz	1500 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
61	77.9	84.2	86	76.3	83	71.5	56.3	64.8	29.3
58.9	62.9	60	55.7	54.4	54.9	53.4	51.7	30.7	33.1
63	79.6	81.1	79	76.8	77.8	69.6	69.6	63.8	37.6
57.5	63.3	52.4	52.2	51.9	63.6	59	54	58.6	21.2
58.3	70.8	68.9	66.2	63.4	62.8	61	56.5	36.4	24
56.3	65.7	64.9	65.8	76.7	75	76.5	72.8	59.5	37
65	80	79.6	73.8	77.5	86.7	72.8	66	28.3	27.7
58.2	67.7	68.7	65.3	64.6	70.5	67.2	61.1	30.4	20.1
52.5	66.8	64.2	54.6	57.2	71.4	64.6	57.5	31.8	13.9
77.2	89.8	89.4	86.7	79	78	71.9	61.1	21.6	17.6